INVESTIGATION OF NOVEL CAPACITORS FOR PULSE POWER APPLICATIONS

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ABSTRACT

Two types of high energy density, double layer capacitors of bipolar construction were evaluated under pulse conditions. One capacitor is a commercial component for use in computer power backup circuits. It was found that allowing interpulse timings of hundreds of milliseconds allowed the battery action of such components to restore to nearly full charging voltage. Operating the components under single charge, multiple discharge pulse conditions was very successful. High equivalent series resistances (ESR) were observed, however, suggesting future problems in applying such components to highly underdamped, ringing circuits or circuits where efficient energy transfer from storage to load is necessary.

INTRODUCTION

The Army has requirements for high energy density capacitors for energy storage purposes. In addition to the highly visible requirements for electric guns, there are additional requirements, such as:

- distributed array radars
- expendable decoys and jammers
- missile seekers
- high power microwave expendable transmitters
- short term burst power for motors, for use in the actuation of turrets and suspensions for combat vehicles

These applications are, in a sense, extensions of the common uses of high capacitance components, currently used to provide backup power to computers. Our experiments used such a commercial computer capacitor, as well as an experimental prototype of a capacitor designed for use in electric guns. The significance of these experiments was to operate the components in a pulse mode.

The capacitors under study were of the double layer type, an illustration of such is shown as Figure 1. These components use activated carbon electrodes, whose porosity creates a large plate surface area, and a chemically active interplate region, which produces an extremely thin (on the order of 1 nanometer) diffuse double layer dielectric. This combination produces extremely high capacitance. The two devices studied were each approximately one-half farad in capacitance. The thin dielectric layer, however, limits the device voltage. The commercial unit was rated at 11 volts. The prototype was rated at 100 volts.

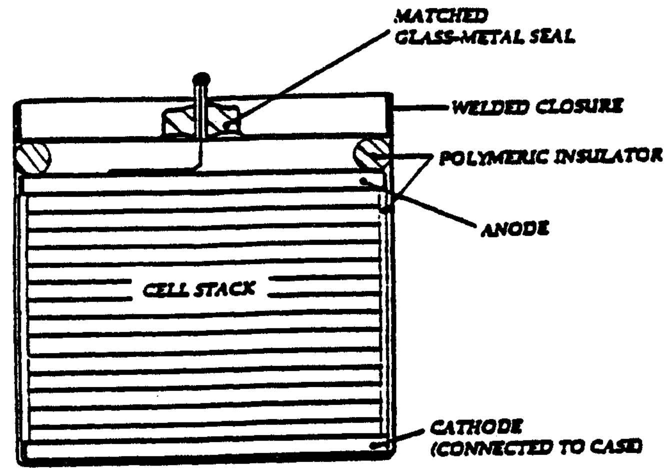

Figure 1. Section view of double layer capacitor.

EXPERIMENTAL APPARATUS

The experimental apparatus is shown in Figure 2. A power supply, of relatively low voltage and constant current, was used to charge the device under test, then disconnected from the device by means of a mechanical relay. The device under test was then discharged via a solid state switch through a resistive load. The solid state switch was used in order to precisely control the discharge time of the device under test, a feature that proved very useful. Pulse discharge width was variable from 1 microsecond to one second, and repetition rate was variable from single shot to 100 kHz. The circuit is completed by a shunting dump circuit, which was used to rid the device under test of any residual charge after the main discharge, as well as as a safety feature.

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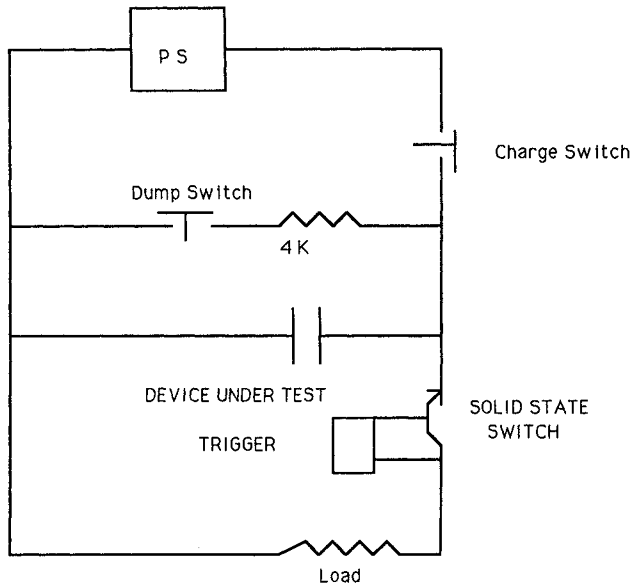

Figure 2. Experimental apparatus schematic.

Voltage was measured by a high impedance probe across the load. System current was measured by means of a current transformer in the discharge circuit.

EXPERIMENTAL RESULTS

For each capacitor, an evaluation was made by charging the capacitor at a constant current to a specified voltage, integrating the current over the charging time, thereby obtaining charge, and solving $Q = CV$ for capacitance, where Q is charge and V is charging voltage. A representative curve is shown as Figure 3. It was found that device capacitance, for both the commercial and prototype units, varied with the applied voltage, as shown in Table 1. Using the last set of values for the commercial capacitor, the volumetric energy density was calculated to be 3.6 MJ/cubic meter and the gravimetric energy density was calculated to be 0.346 kJ/kg.

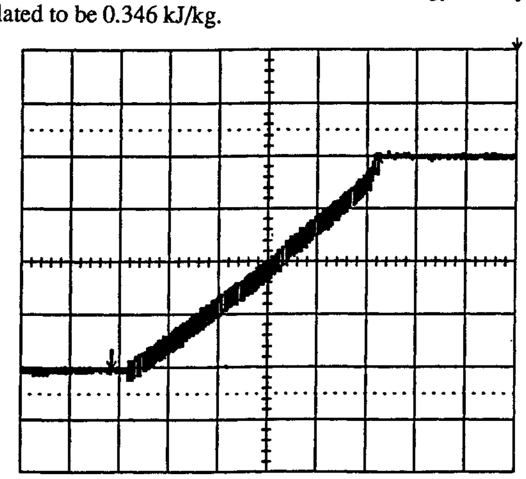

Figure 3. Measurement of capacitance of commercial capacitor, by charging at constant current. Current is integrated over time, yielding charge, and capacitance is computed by $Q = CV$, where Q is charge and V is charging voltage. Vertical axis: 2 V/div and horizontal axis: 2 s/div.

TABLE 1

Variation in Capacitance with Respect to Voltage

COMMERCIAL CAPACITOR

Voltage	Capacitance
6.00 V	0.354 F
8.06 V	0.401 F
11.16 V	0.417 F

PROTOTYPE CAPACITOR

Voltage	Capacitance
10 V	0.292 F
20 V	0.385 F
40 V	0.406 F
60 V	0.420 F
80 V	0.424 F
100 V	0.437 F

Equivalent series resistance was measured by discharging the device under test into a short circuit and measuring peak discharge current. The commercial components tested had equivalent series resistance on the order of one-half ohm. The prototype units tested performed better, with an ESR an order of magnitude lower than the commercial units.

Of particular interest were the pulse characteristics of the commercial unit. Figure 4 shows the results of a discharge pulse of 1 millisecond duration, the order of magnitude required for electric guns. The device under test recovered to within 10 percent of charging voltage within 250 milliseconds and reached full voltage within 300 milliseconds. The load for this test was on the order of one-half ohm. Only 27% of the energy stored in the capacitor was transferred to the load.

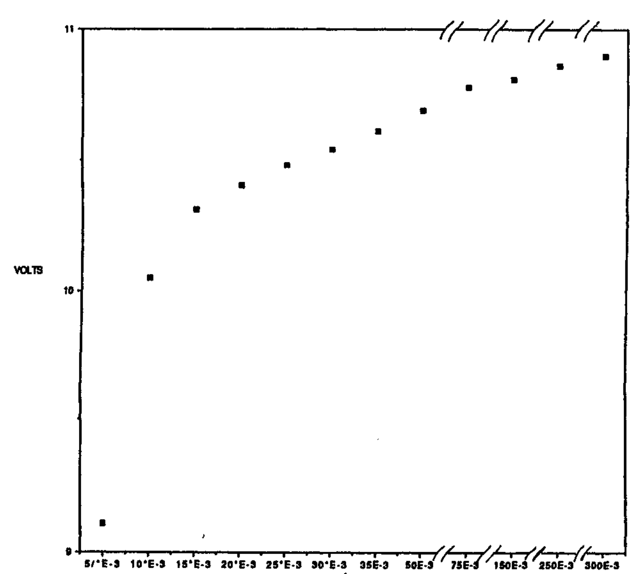

Figure 4. Recovery characteristic of commercial capacitor after 1 millisecond discharge pulse.

It was found that the discharge energy of the commercial capacitor was strongly dependent on the discharge pulse width. Figure 5 shows the efficiency of discharge as a function of recovery time between pulses. The discharge efficiency is defined as discharge energy over charge energy.

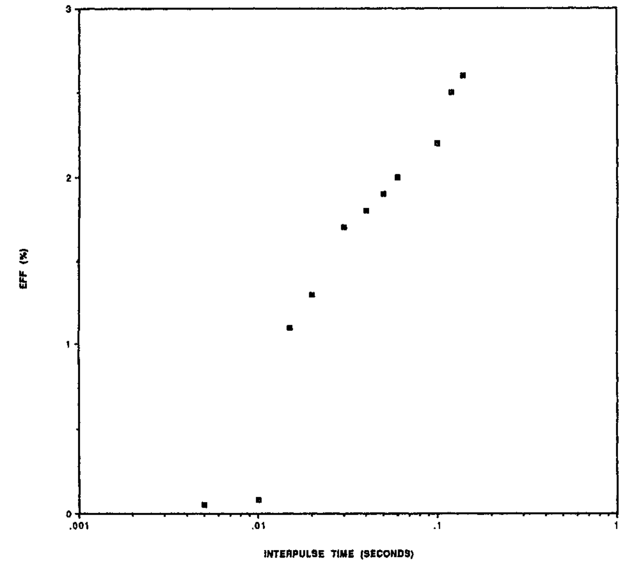

Figure 5. Efficiency as a function of recovery time between pulses, for the commercial capacitor.

It was found that allowing a relatively long interpulse time increased the discharge efficiency in both prototype and commercial units. This takes advantage of the previously mentioned recovery time after discharge. We attribute the second phase of the recovery to a battery like phenomenon in capacitors of this type. Figure 6 show an example of this phenomenon, for the commercial unit. In this case, discharge efficiency increases from 2.2% to 28% as we went from single to multiple pulses without recharging between pulses. This is in total energy applied to the load. Similar measurements of the prototype yielded similar discharge efficiencies. If the application of the devices will permit an interpulse time in the hundreds of milliseconds, then these devices will be viable as energy storage components.

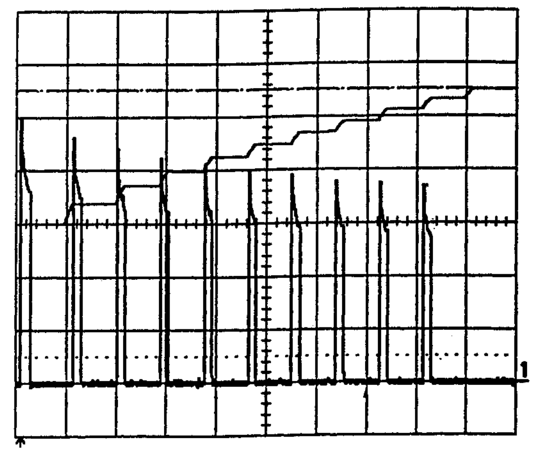

Figure 6. Pulse waveforms (bottom trace, 1 V/div) and total energy (top trace 0.65 J/div) of burst type discharge. Horizontal axis: 50 ms/div. Energy is obtained by integrating the pulse voltage and current product over time. Note the increase with each pulse. There is no recharging between pulses.

CONCLUSIONS

Capacitors of this type show promise as energy storage devices. If the long interpulse times, measured in hundreds of milliseconds, can be tolerated, then these devices may find application as short term, burst mode pulsed energy storage elements. The key factor is the relatively low efficiency of the devices. A commercial electrolytic capacitor, by way of comparison, has an efficiency roughly two and one-half times that of the double layer capacitor. If the energy loss can be tolerated, then these are viable units. By toler ated, it is meant that the capacitor can either tolerate the dissipation of energy, or can have the energy removed in an efficient manner.

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